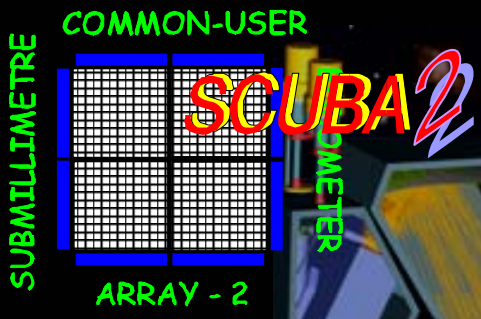


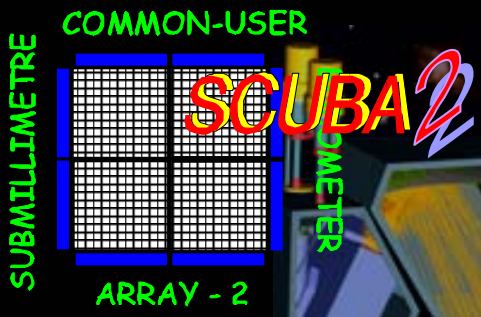
SCUBA-2: a 10 000-pixel submillimetre camera for astronomy

Talk given at the 32nd International Conference on Infrared and Millimetre waves, Cardiff, 5th September, 2007

Adam Woodcraft
On behalf of the SCUBA-2 consortium
http://woodcraft.lowtemp.org
SUPA, University of Edinburgh/ATC

Science & Technology Facilities Council
UK Astronomy Technology Centre

SUPA
Scottish Universities Physics Alliance



Background

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Sub-mm astronomy

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- Sub-mm astronomy: wavelengths of a few hundred μm
  - Typically in “windows” around 450 and 850 μm (670 and 350 GHz) – atmosphere is largely opaque
- Lets us see cold things: peak in 10-K blackbody around 300μm
  - e.g. objects in formation (stars, planets, galaxies…)
- Also lets us see far away (red shifted) warmer objects: peak in 40 K blackbody at red shift Z=3 is at 300 μm
- Sub-mm emission usually “optically thin”; so we see the interior rather than just the surface of objects

The Submm Revolution

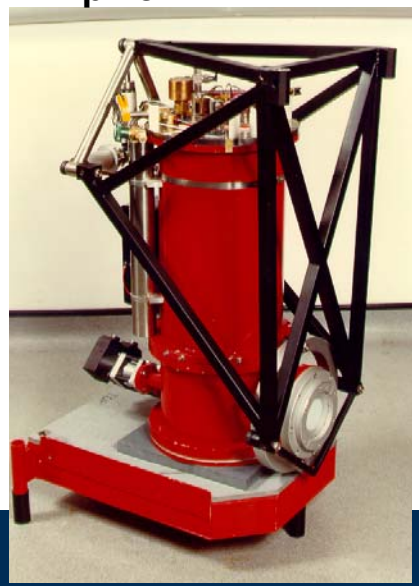
- Huge revolution over the past decade – very limited access to this region of the spectrum before

- SCUBA(1) on JCMT has been largely responsible for this:
  - Built at UK ATC in Edinburgh
  - At the peak of its productivity had a citation rate to rival that of the Hubble Space Telescope
  - Operated 1997-2005

Beyond SCUBA

- Instruments limited by small number of pixels
  - Gone from 1 pixel to 100s in a decade – need more!
  - Less than 1% of the FIR/submm sky studied in any detail
- BUT: Detector development in relative infancy
- No big military or commercial applications (as yet…)
- Detectors not available commercially

UKT14
1986-1996
1 pixel



SCUBA
1997-2005
128 pixels

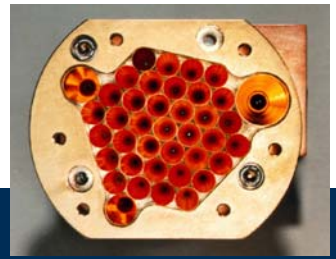
SCUBA-2
2007+
10240 pixels

Detectors

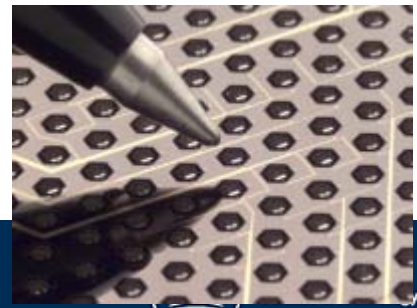
- Most sensitive detection method is to use bolometers
  - Measure temperature rise due to absorbed radiation
  - Respond to wide wavelength range – define with filters
- Traditionally use NTD germanium thermistors
  - BUT: not background limited for best telescopes
  - Hard to make large arrays:
    - Ge chips have to be individually mounted on each pixel
    - Can't multiplex without prohibitive noise penalty
    - Separate wiring and read-out electronics for each pixel required

SCUBA individual pixel

SCUBA focal plane



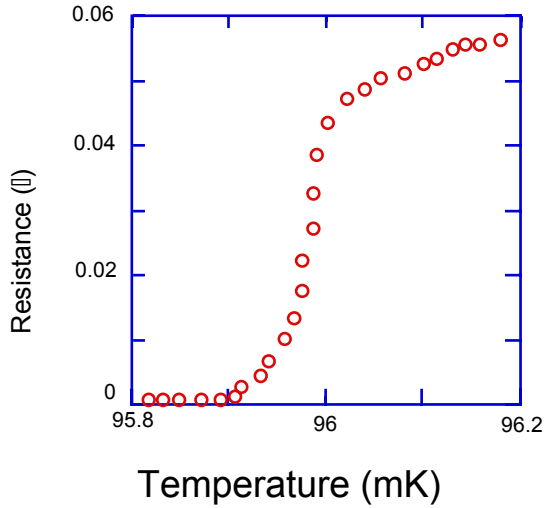
SPIRE array – multiple pixels on one silicon wafer



Solution

- Sensitive (resistive) bolometer requires large dR/dT

- Very large dR/dT through superconducting transition
- Basis of TES (transition edge sensor), operated in superconducting transition

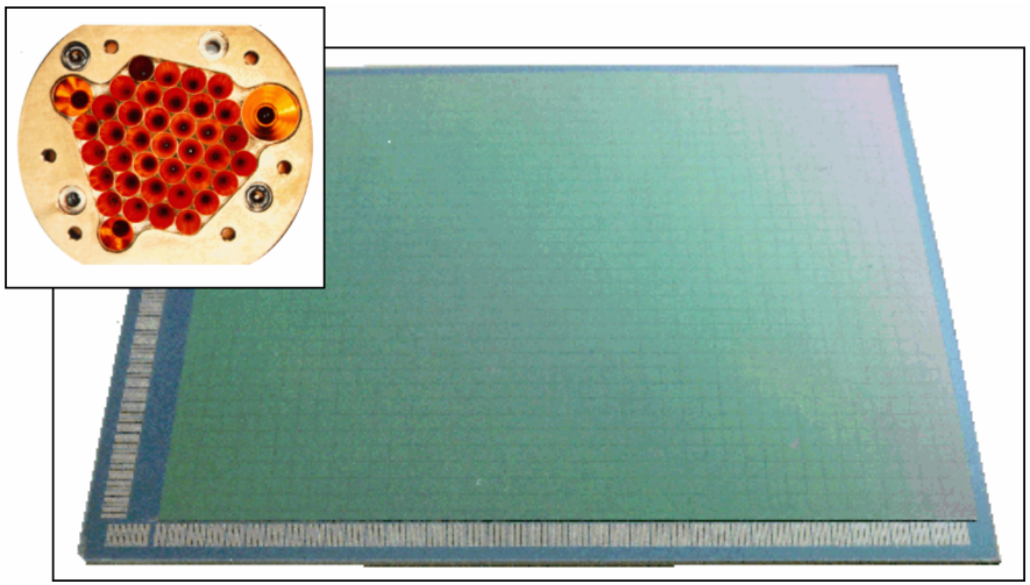


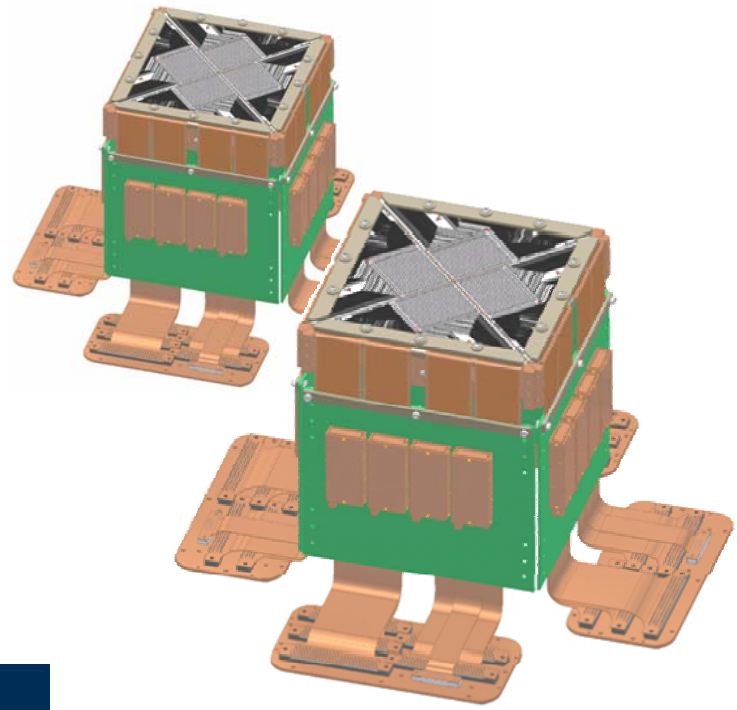
- Other advantages:
  - TES sensors can be deposited on silicon wafer:
    - Entire array can be constructed with no operations at the level of a single pixel
  - Detectors can be multiplexed with good performance

SCUBA-2 detectors

- Simultaneous dual colour imaging (450 and 850 μm)
- Each focal plane made up of four 1280 pixel sub-arrays
- Pixels use Mo/Cu bi-layer superconductors
  - Weak thermal link provided by silicon nitride membrane

SCUBA-2 sub-array (SCUBA array inset)

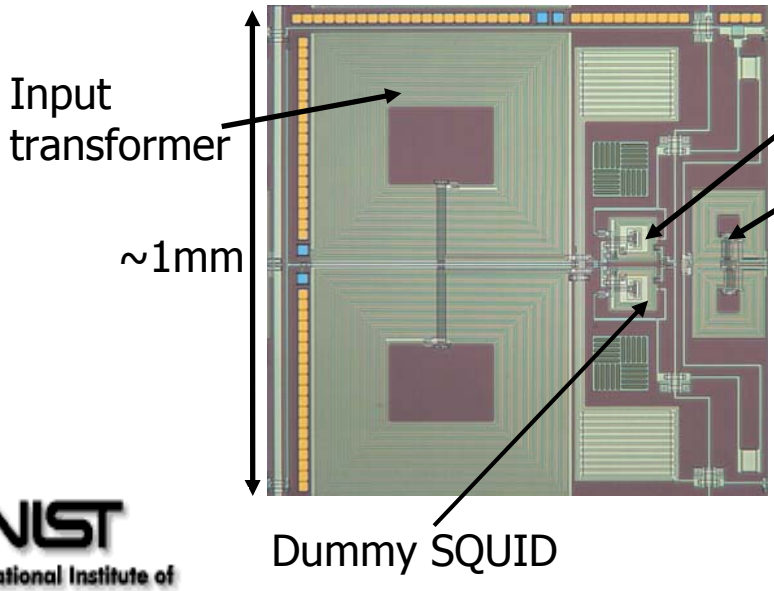


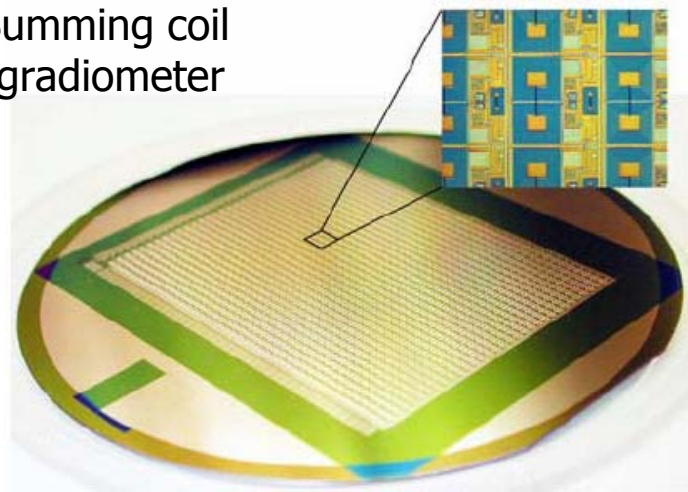


SCUBA-2 detector units

Multiplexing

- Previous (much smaller) TES arrays have had separate detector and SQUID multiplexer chips
- Instead, use new compact configuration: in-focal-plane (TDM) multiplexer
  - MUX wafer is bonded to detector wafer
  - Indium bump bonds provide electrical connections





A full-sized (40 × 32 pixel) multiplexer wafer

Sub-array module

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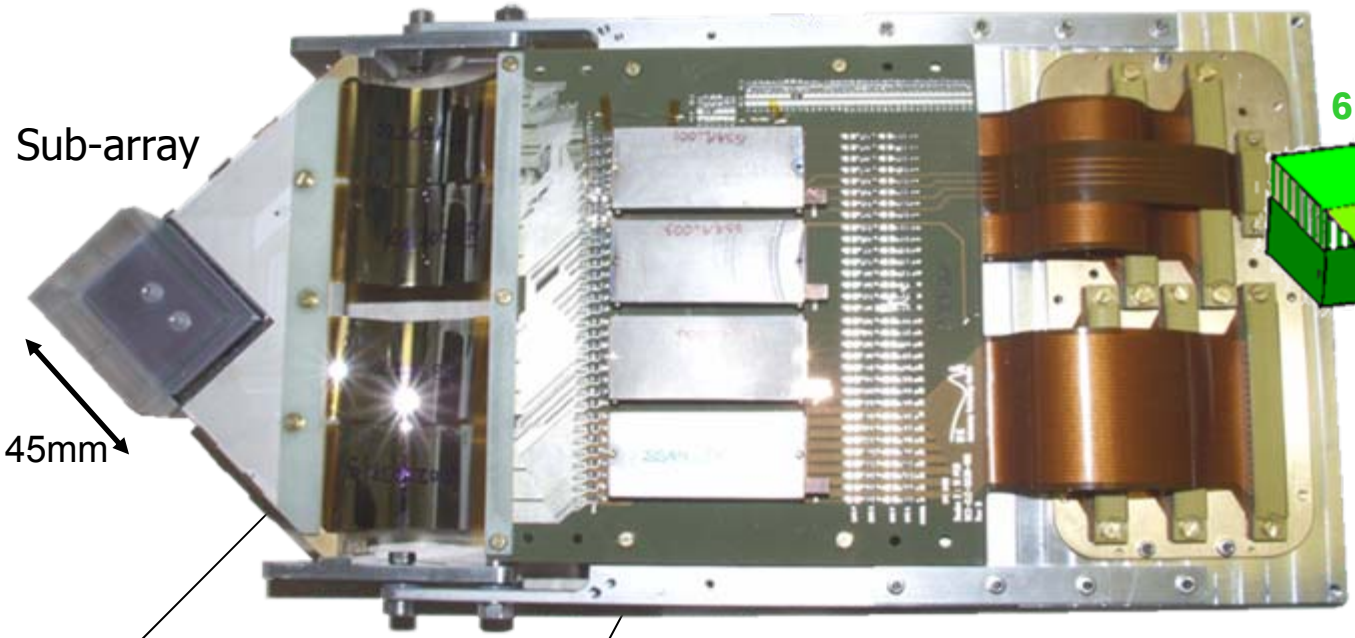

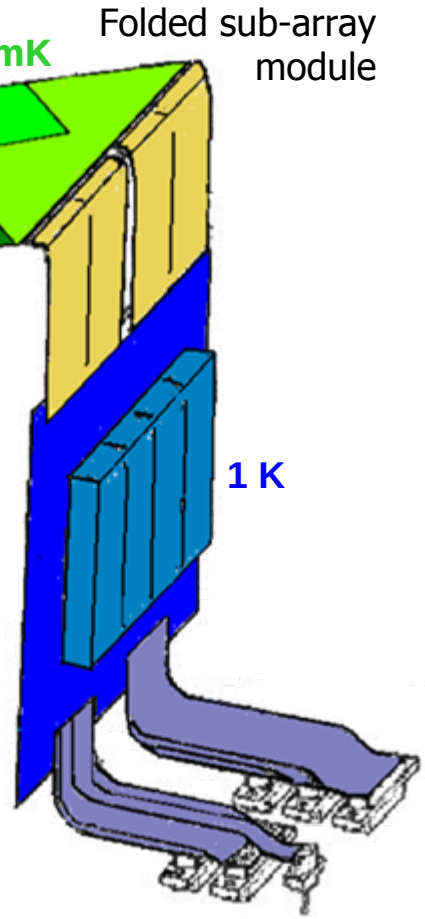

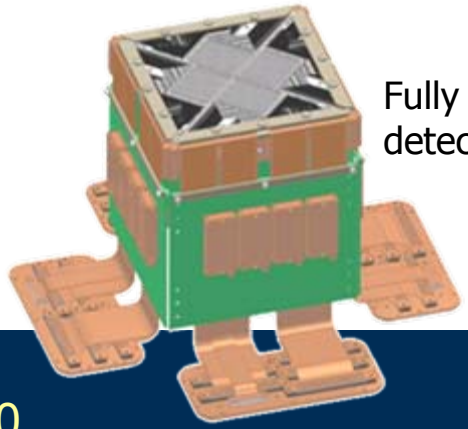

Fully populated detector unit

Detector unit with one prototype array installed

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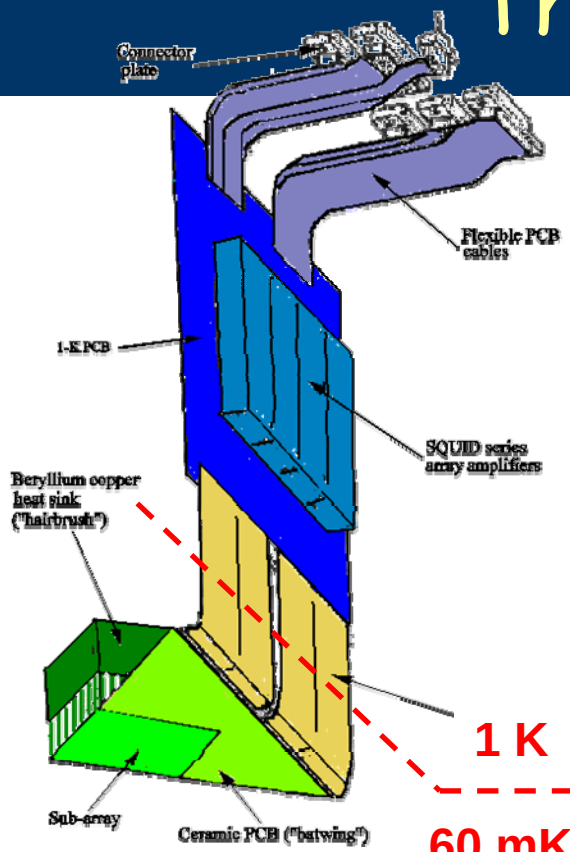
Thermal diagram



More information on the low temperature thermal design in Woodcraft et al Proc SPIE 5498, 446-454 (2004)

http://reference.lowtemp.org/woodcraft_scuba2thermal.pdf

1-K PCB

1 K

60 mK

Kapton/niobium ribbon cable

Hairbrush

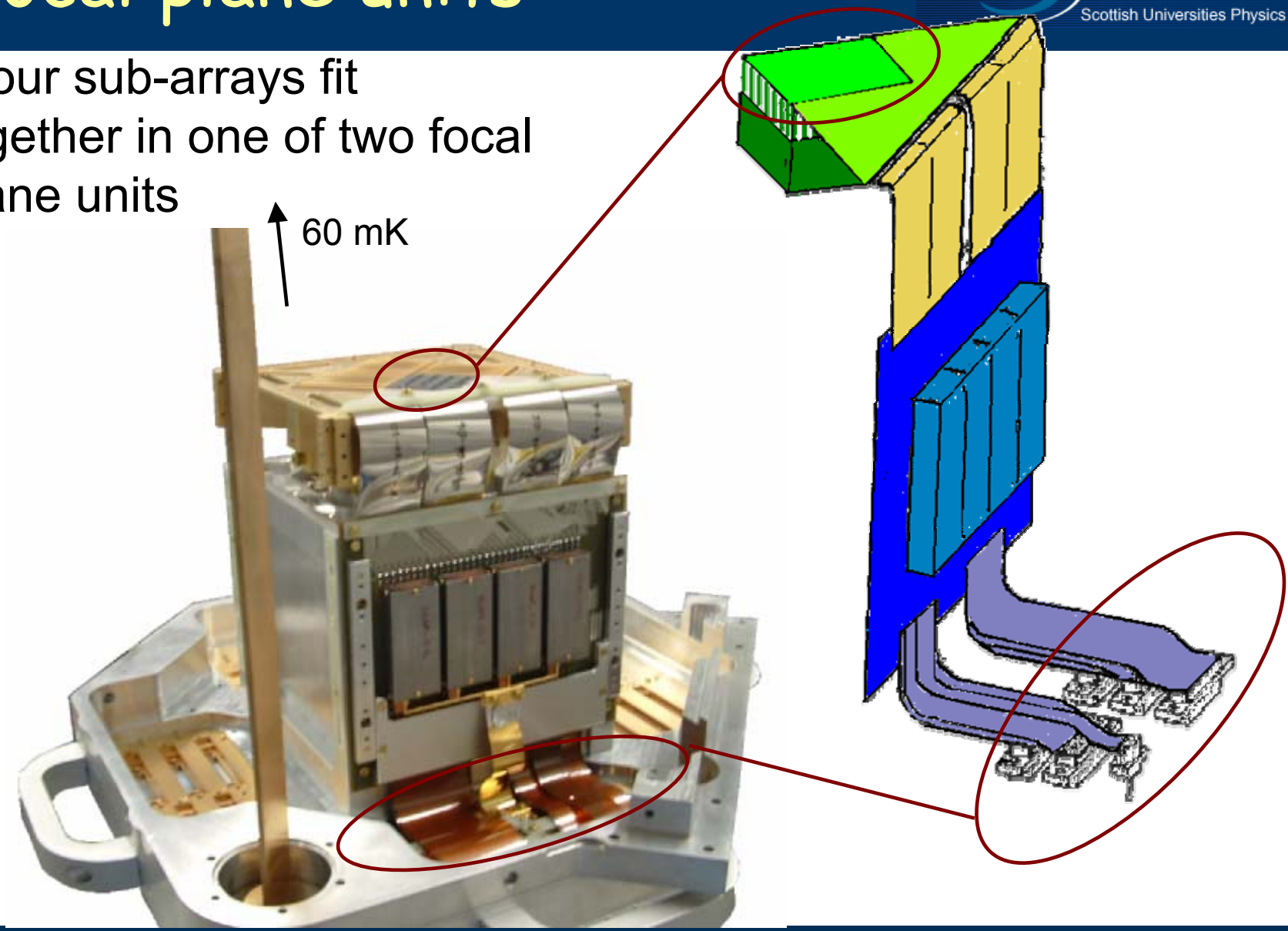
Multiplexer

Detector

Ceramic PCB

Focal plane units

- Four sub-arrays fit together in one of two focal plane units



Cryostat design

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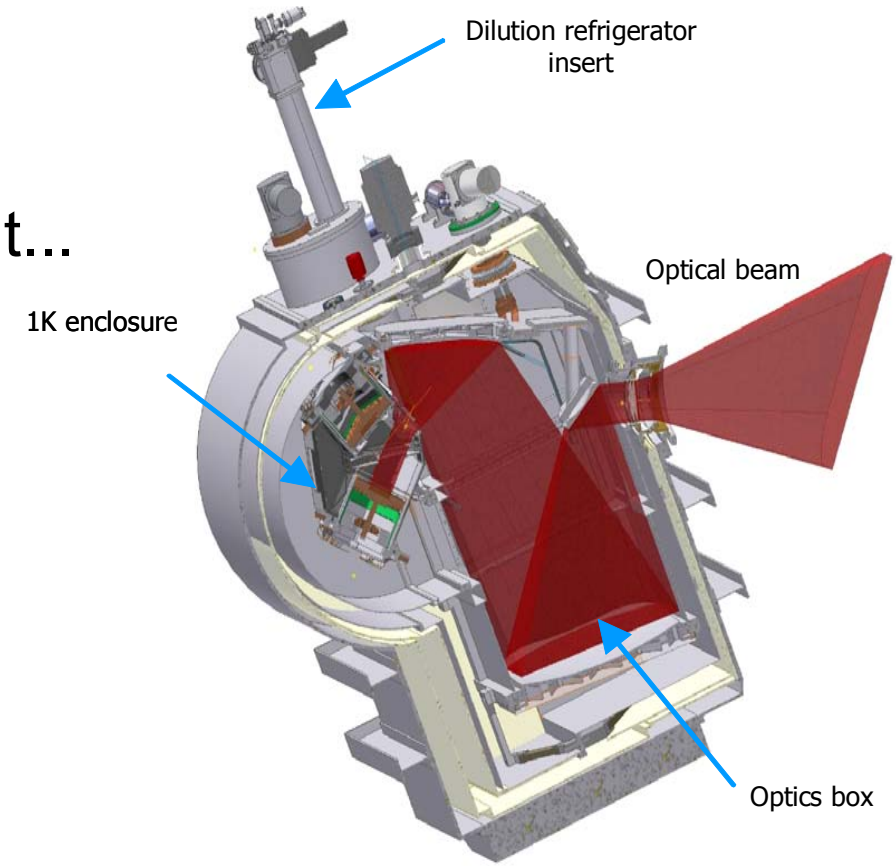
Key challenges:

- Cooling 300 kg of optics to 4K
- Getting all the signal cables out...
- Stray light control
- Magnetic shielding of SQUID circuitry in the multiplexer
- Liquid-cryo free operation



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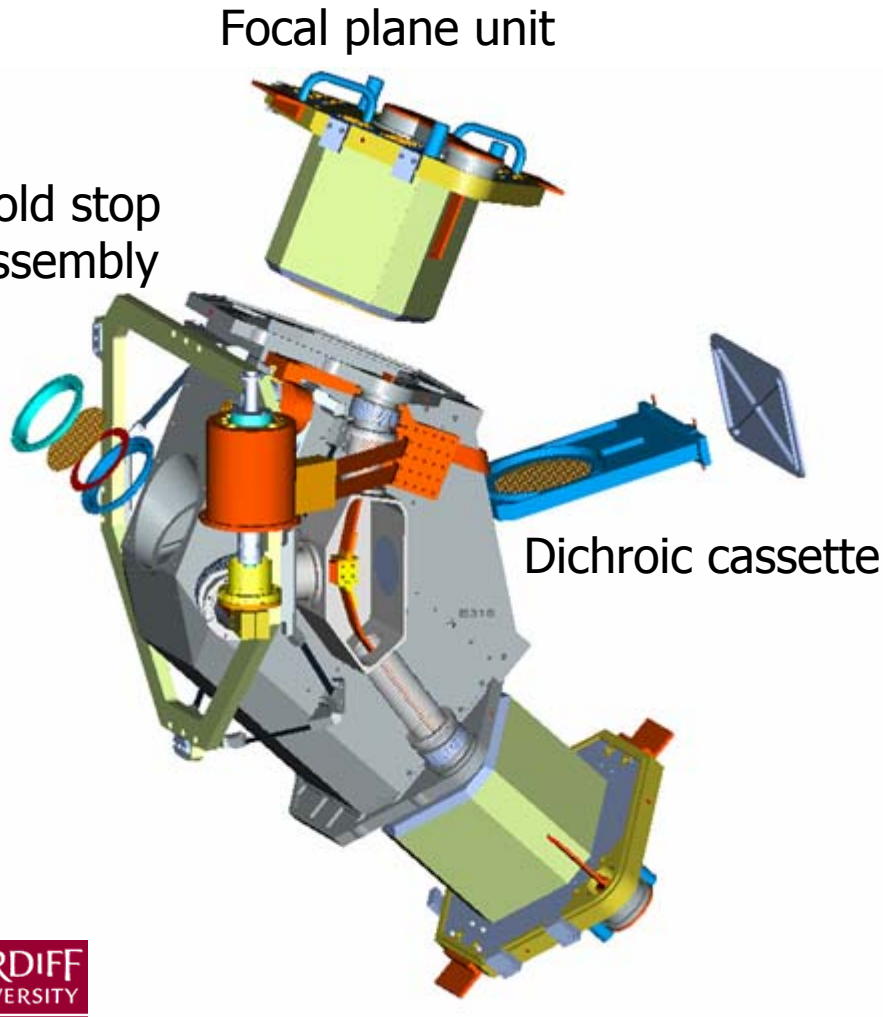
Cryogenics

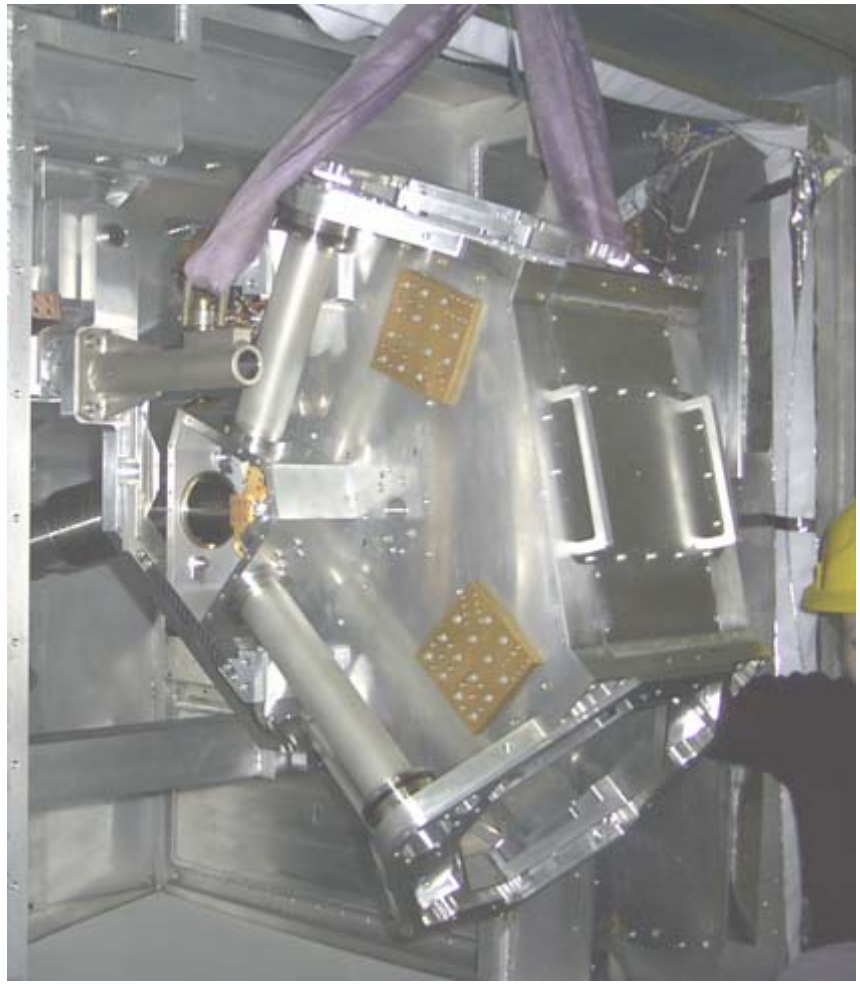
- Arrays must be operated from heat sink at 0.06 K
  - Cooling provided by dilution refrigerator (Leiden Cryogenics)
  - Operates from temperature of 4 K
    - Traditionally provided by bath of liquid helium
    - Instead use mechanical (pulse tube) cooler to reduce running costs
    - First commercial “dry” dilution refrigerator(?)
- Two more pulse tube coolers used for rest of instrument

Leiden Cryogenics BV
Leader in LT Techniques

Dilution refrigerator insert

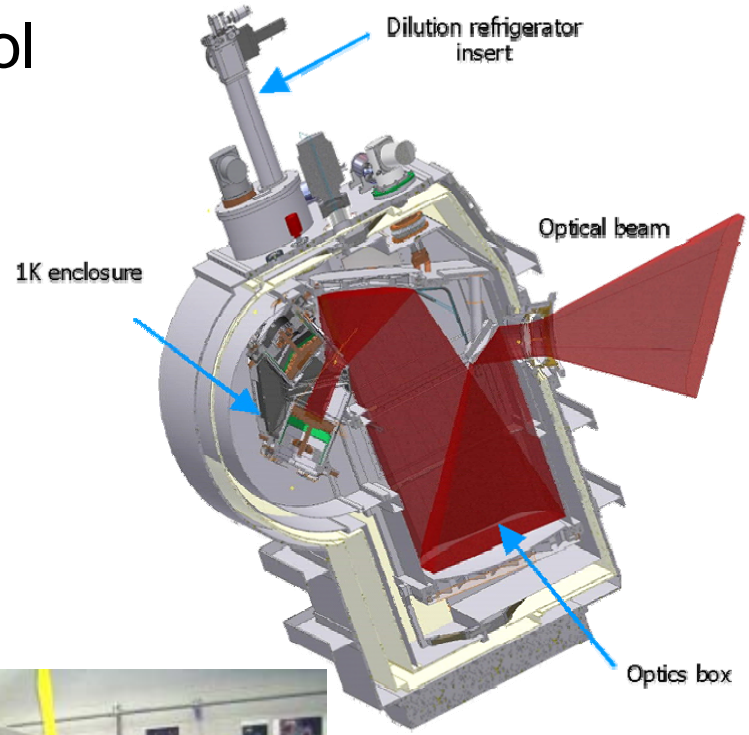
1K enclosure ("1K box")





Size

- Instrument size driven by need to cool large mirrors to below 10 K (to reduce thermal background on arrays)



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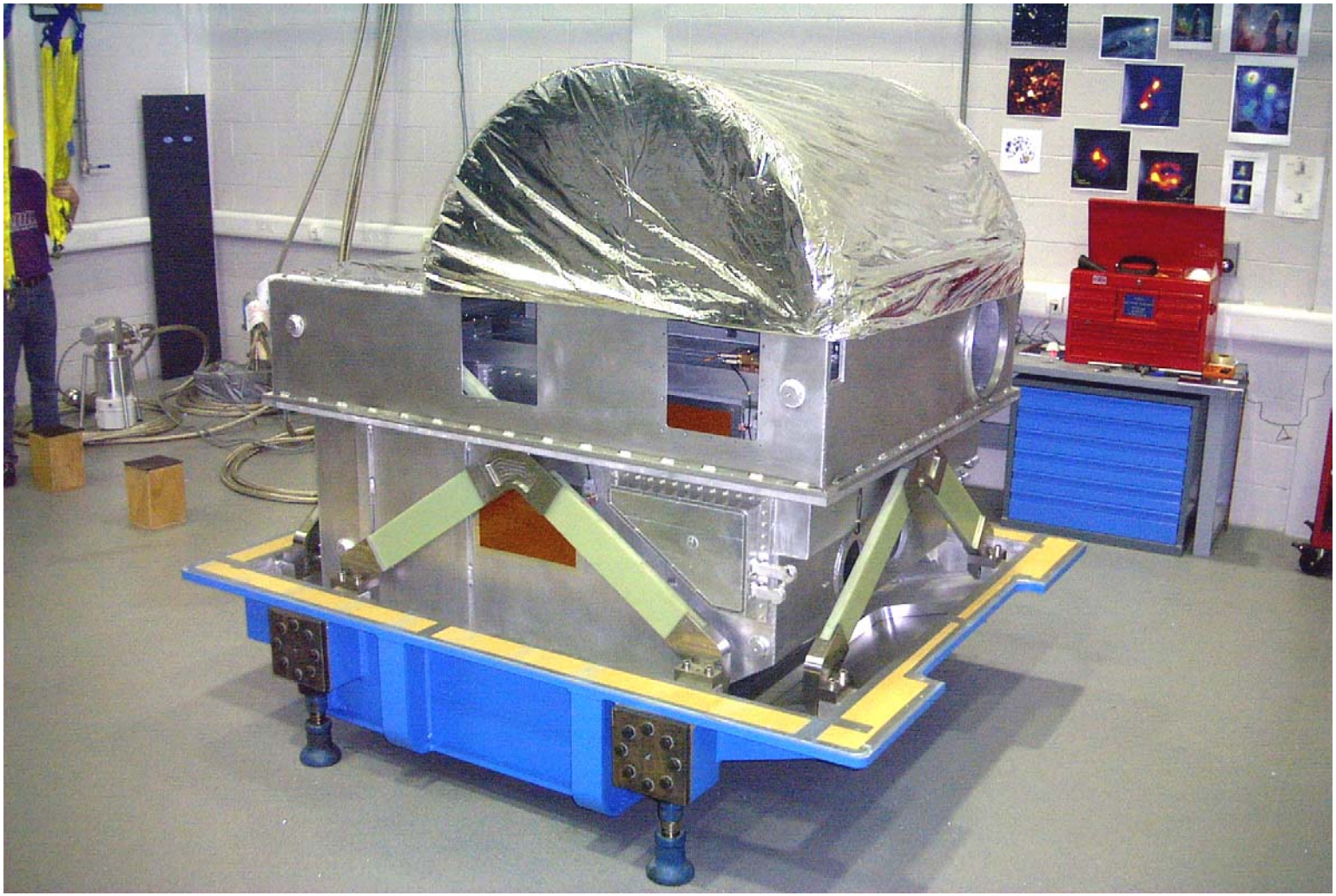
Installing the mirrors

Installing the optics box

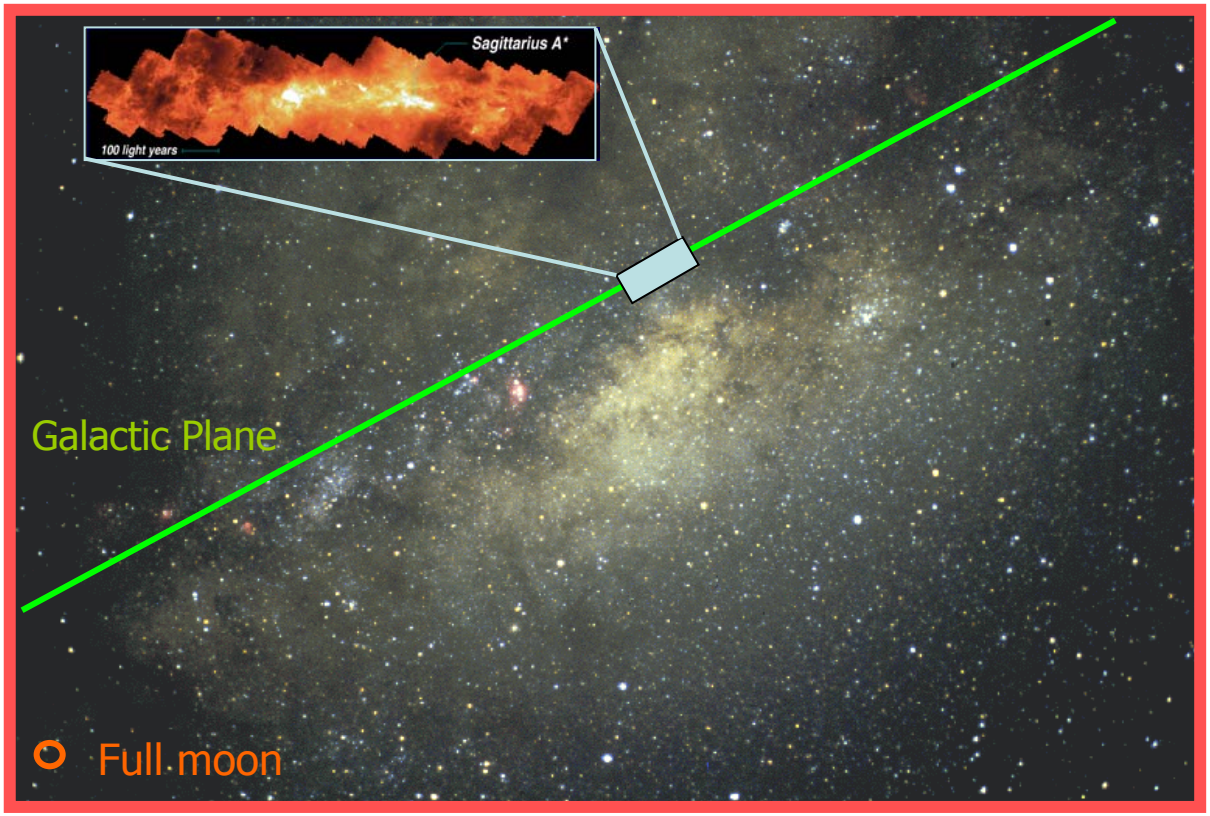
Radiation shields



Vacuum vessel

Onto the telescope…

Survey potential



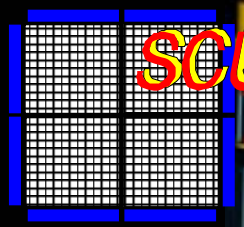
SCUBA Galactic Centre Survey

~15 shifts (or 120 hrs) over 2 years

of excellent weather telescope time

SCUBA-2 could map the ENTIRE AREA shown above (red rectangle) in just a couple of hours to the same S/N...

SUBMILLIMETRE COMMON-USER



ARRAY - 2

SCUBA2

Status

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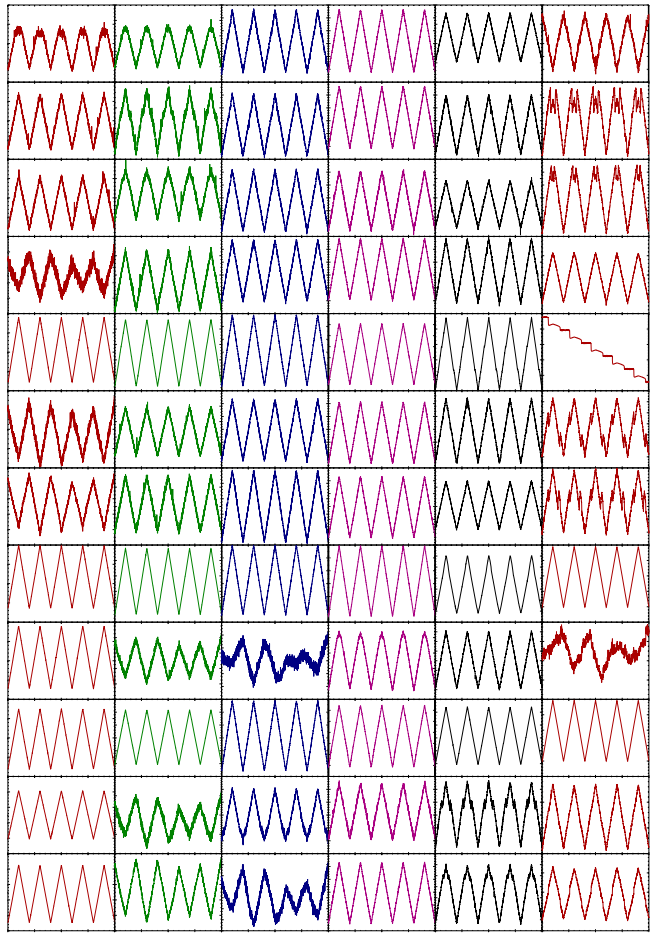
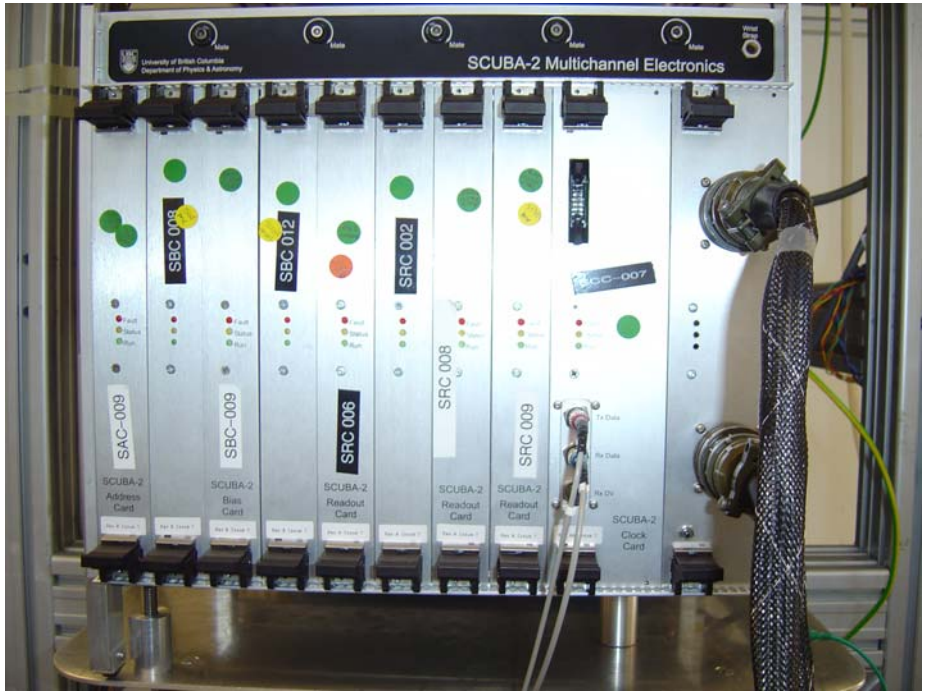
Array measurements

- TES readout is complex
- Each pixel read through three SQUID stages
  - Each stage has to be set up with appropriate parameters
  - Previously reported results taken with manual setup, limiting number of pixels measured
  - Largest number: 72 pixels

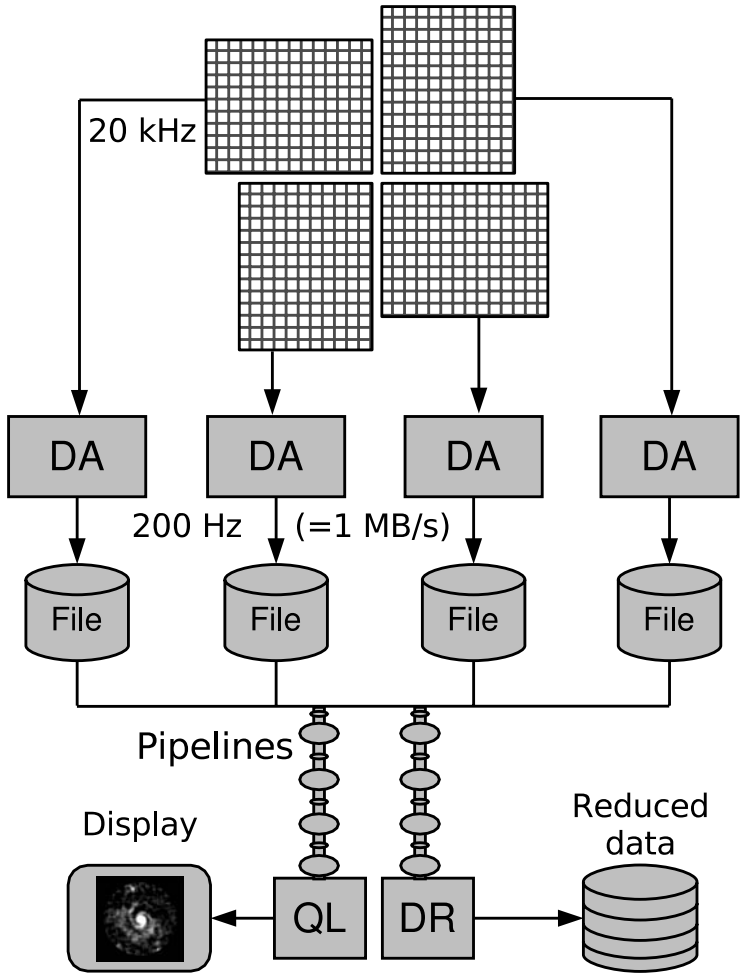


More information on previous measurements:
Woodcraft et al., Rev. Sci. Inst. 78, 024502 (2007)
http://reference.lowtemp.org/woodcraft_scuba2proto.pdf
Woodcraft et al., Proc SPIE 6275, 62751F (2006)
http://reference.lowtemp.org/woodcraft_spie06.pdf

Data acquisition

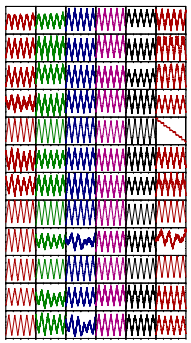


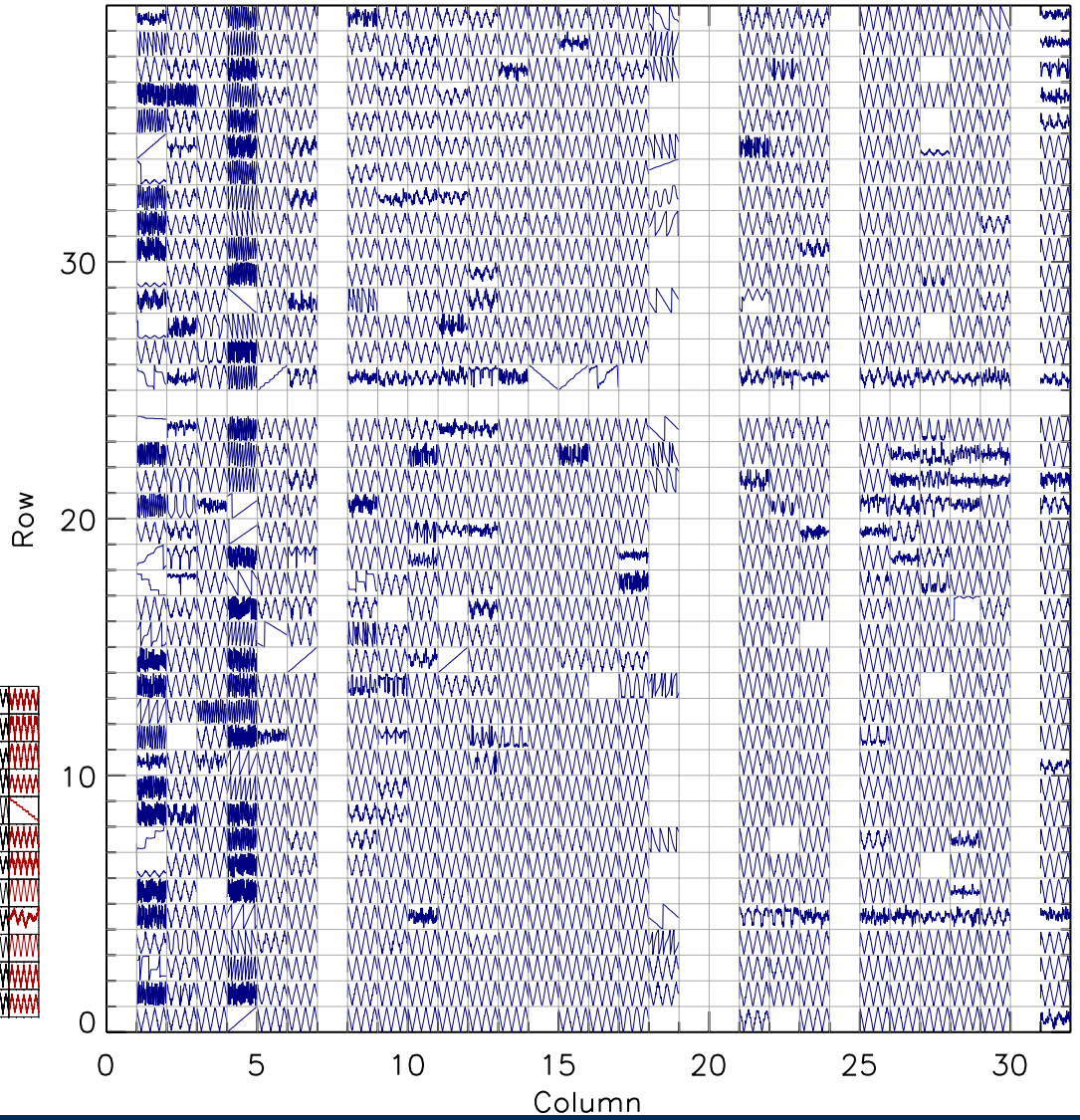
Multi-channel electronics developed by UBC/NIST/UK ATC



Full array measurements

- Now have MCE available to carry out array tests
- Automatically sets up and reads out whole sub-array of 1280 pixels





Yields

- Measured two commissioning grade arrays – one 450 μm and one 850 μm
- Yield: 70% and 40% (respectively)
- Bad pixels almost entirely due to faults on multiplexer wafer
- Multiplexers for science grade arrays have been produced and screened with yield ~ 90%
- Therefore we have confidence that science grade arrays will have acceptable yields

Uniformity

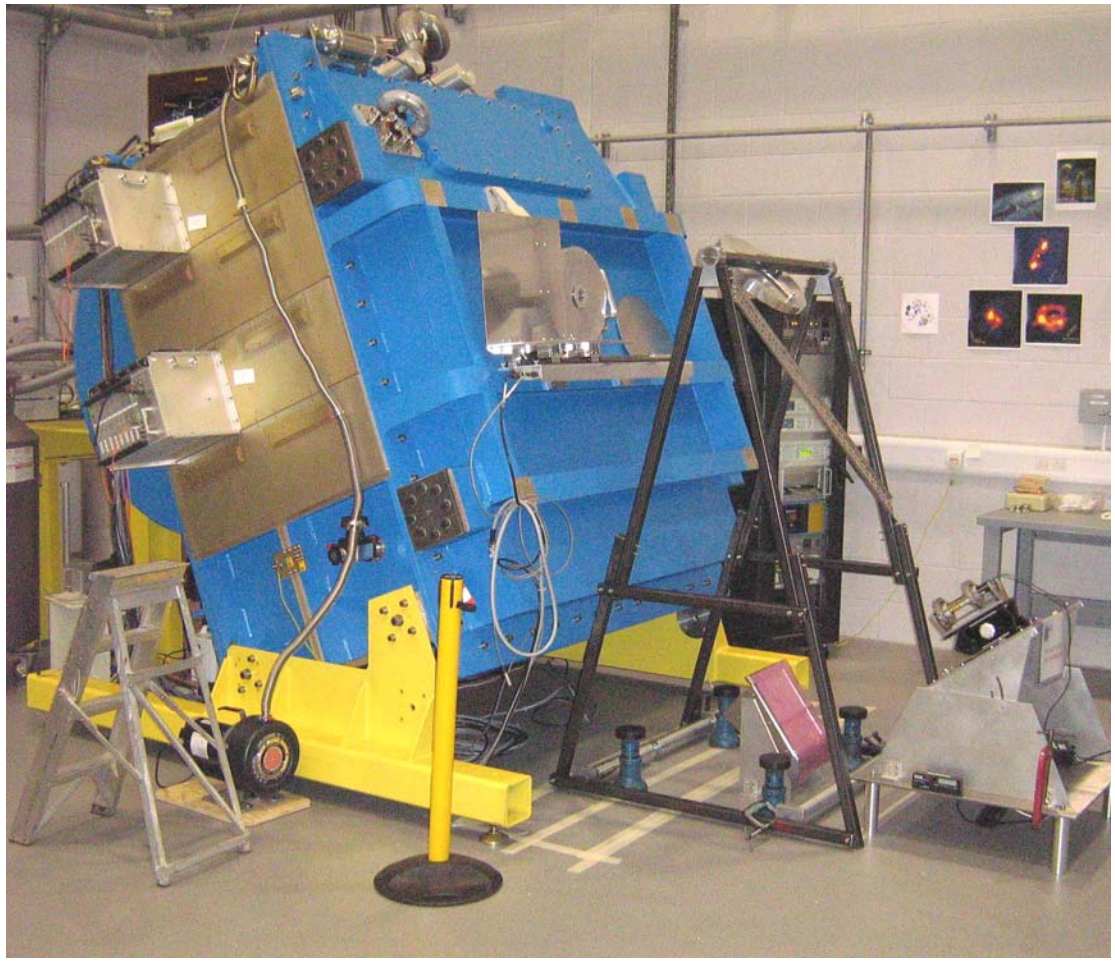
- All pixels in one sub-array are wired in series
- Therefore need uniformity in properties
  - e.g. T_c, thermal conductance, detector resistance
- Too great variation means no single value of bias suiting all pixels
- Test show that both arrays are operable simultaneously
  - Confirms previous tests on small numbers of pixels distributed across arrays

Final instrument

- Detector arrays operating at 100 mK
- Measured optical NEPs of ~2.5 × 10^{-17} W/√Hz
- 10,000+ pixels in two focal planes
- Two arrays installed with remaining 6 to be added in Hawaii

Current status

- Instrument is now essentially complete – nearing delivery standard
- Instrument verification is now underway; optical tests, operational modes etc.



Summary

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- SCUBA-2 will be the first wide-field, ultra-sensitive camera for submm astronomy

- The technology is state-of-the-art and represents a great investment on behave of the funding agencies

- Recent tests show that yield will be acceptable and confirm that simultaneous operation of an entire sub-array is possible

- Delivery to the JCMT is planned for late summer 2007 with survey science starting early next year

Institutions

Science & Technology Facilities Council
UK Astronomy Technology Centre

Instrument design, construction, testing, commissioning: *ATC, Edinburgh*

Multiplexer and TES devices: *NIST, Boulder*

Detector micromachining: *University of Edinburgh*

"1-K box" design and construction, detector test programme, filters/dichroic: *Cardiff University*

Warm electronics: *University of British Columbia,* MUX testing, *University of Waterloo*

Telescope infrastructure: *Joint Astronomy Centre, Hawaii*

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